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Beach and Morphology Change Using Lidar

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PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) describes the use of lidar data in conjunction with beach profile surveys to examine morphologic and volumetric change on a regional scale. The study area includes three counties and over 70 miles of the southwest Florida coastline. The lidar data were obtained from the U.S. Army Corps of Engineers (USACE), Joint Airborne Lidar Bathymetric Technical Center of Expertise. Beach profile surveys were provided by USACE Jacksonville District (SAJ), University of South Florida (USF), and Coastal Planning & Engineering (now CBI Industries, Inc.). The study region is entirely within the SAJ jurisdiction.

The area of interest includes the coastline along the Gulf of Mexico from Clearwater Beach in Pinellas County, FL, to Venice Beach in Sarasota County, FL (Figure 1). Active Federal projects existing within the limits of this study region include the Pinellas County Shoreline Protection Project (SPP) (USACE SAJ 2010), Tampa Harbor Navigation Project (deep draft), the Gulf Intracoastal Waterway (GIWW), Manatee County SPP at Anna Maria Island, the City of Sarasota SPP at Lido Key, Sarasota County SPP at Venice Beach, and a number of federally authorized shallow-draft navigation channels. Local projects exist as well at Longboat Key and at Siesta Key. This effort was supported by the SAJ and the U.S. Army Engineer Research and Development Center (ERDC) through the USACE Regional Sediment Management (RSM) Program.

INTRODUCTION: The southwest Gulf Coast of Florida consists of a barrier island system that has been under development since the early 1900s. At present, most of the shoreline is considered to be urban. The coastal area is directly under the influence of past and present anthropogenic activities including dredging of the passes and GIWW as well as placement of sediments dredged from the passes and offshore sources onto the beach. As a result of the active and impactful hurricane seasons of 2004 and 2005, most of the beaches in Pinellas, Manatee, and Sarasota Counties were nourished from 2005 to 2009. SAJ sought to use lidar data collected from 2006 and 2010 to examine morphologic and volumetric change between the two time periods. The treatment of the lidar data is described herein, and a regional sediment budget was developed from these data as discussed in a forthcoming CHETN[1].

Using lidar data to develop a sediment budget over regional scales is advantageous because the topographic and bathymetric data sets are synoptic, whereby sediment mass across the region can be conserved. Issues can arise using disparate beach profile surveys that have been obtained over different time periods as sediment may have shifted from one region to the next. This increases the possibility of introducing error such as counting the same volume of sediment twice as it

[1] Legault, K. R. In preparation. Pinellas, Manatee, and Sarasota Counties, regional sediment budget. ERDC/CHL Technical Note. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

moves in the alongshore. Volumes of sediment can be discounted completely as sediment is transported out of the control volume and region of interest. The entire extent of the regional sediment budget is shown in Figure 1. The April 2006 to October 2010 timeline for all of the project and data measurements used for the analysis is shown in Figure 2.

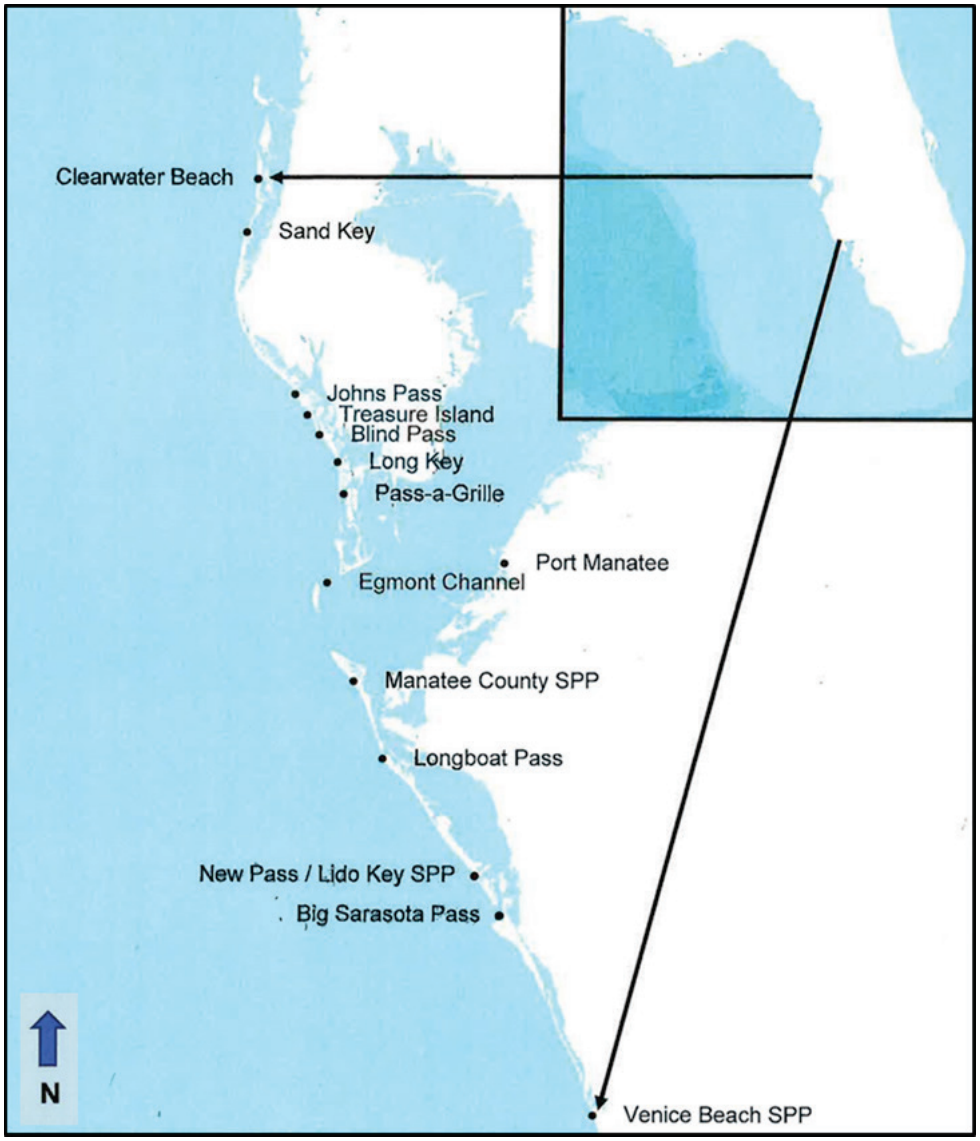


Figure 1. Active USACE SAJ projects in Pinellas, Manatee, and Sarasota Counties, FL.

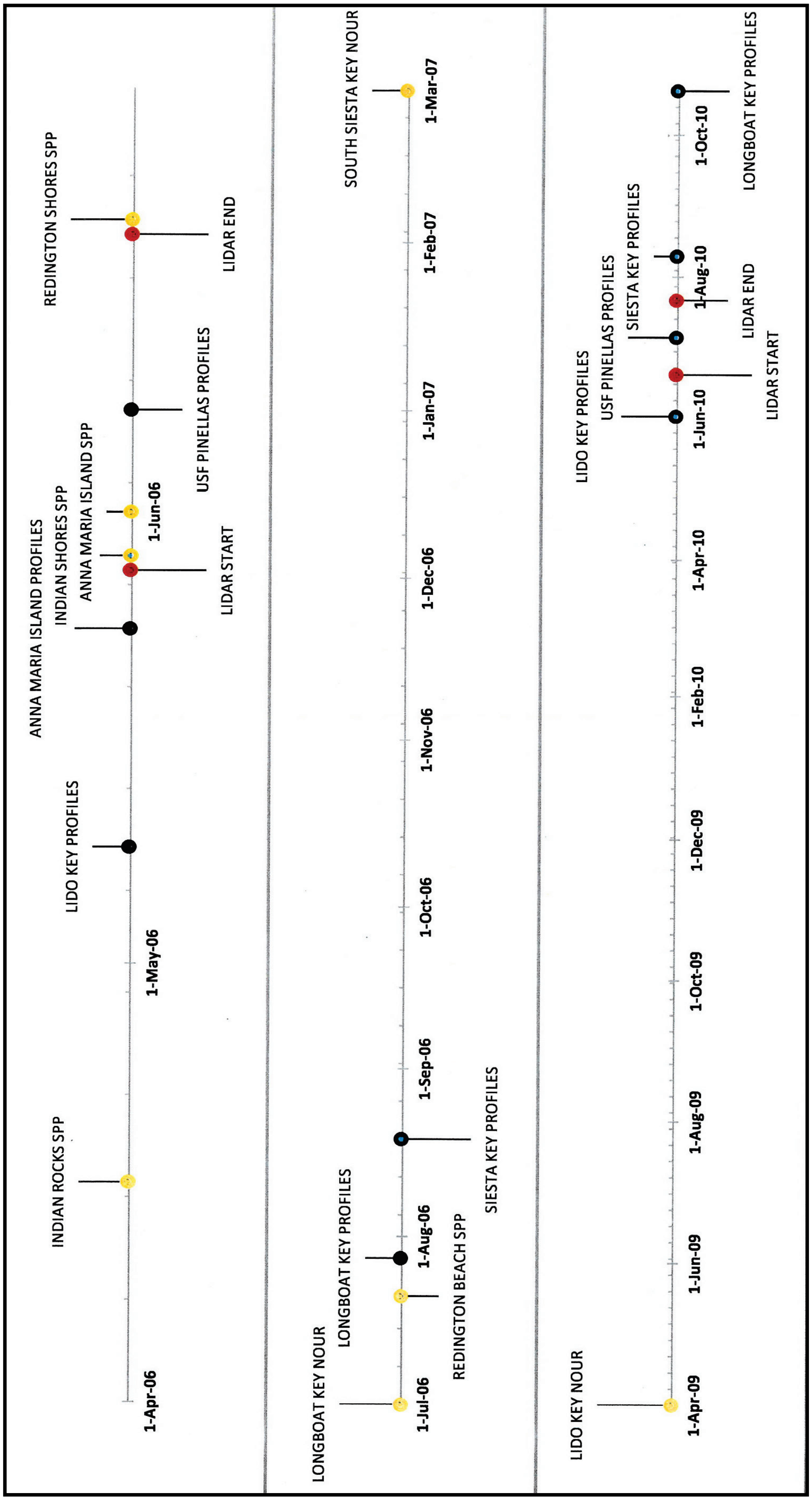


Figure 2. Timeline for Federal and local shore protection projects, lidar acquisition, and beach profile measurements.

METHOD: The large number of Federal projects along the southwest Gulf Coast of Florida warranted an RSM approach to determine best sediment management practices amid the complex combination of natural and anthropogenic sediment movements. To update the sediment budget for the region, SAJ sought a method for calculating the change in beach volume density for the entire region for the post-hurricane epoch of 2006–2010. Synoptically acquired lidar data were determined to be appropriate.

Lidar data collected in 2006 and again in 2010 were compared with measured beach profile data across the entire region to determine if any discernible difference existed between the lidar and beach profile data. Beach profile data were obtained from the Coastal Research Laboratory at USF. These data were taken bi-monthly from 2006 to present and contained over 40 different data sets for the entire region. Profiles were taken at each Florida Department of Environmental Protection R-monument, covered the subaerial beach, and extended at least 1 mile offshore (bathymetry). Beach profile data were selected for the analysis when obtained within the window when lidar was being flown or within 3 weeks of the lidar window. All beach profile data from USF were measured within the lidar window.

Three separate projects were created using the Surface-water Modeling System (SMS) (Aquaveo 2013) software for Pinellas, Manatee/Sarasota, and south Sarasota Counties (Table 1). Lidar data were imported as (x, y, z) scatter points into the Scatter Module of the SMS (Figure 3) decimated by 5 meters (m) in the cross-shore and 50 m in the alongshore. Beach profile data were also entered as (x, y, z) scatter data (Figure 4). Lidar data were interpolated to the beach profile data scatter set (Figure 5) and were differenced from the beach profile data (Figure 6). Figures 3 through 6 show the data for the 2006 time period. The same treatment was used for the 2010 data.

The differenced data were imported to the Matlab Statistics Toolbox (Mathworks). The data were displayed as a histogram. A Student's t-distribution was fit to the histogram using the Distribution Fitting Tool (examples shown in Figures 7 and 8). The t-distribution is symmetric and bell shaped like the normal distribution and is useful for examining data distributions with heavier tails (more prone to outliers) than the normal distribution. In the surf zone, there is a risk that the signal from the lidar does not accurately measure the seafloor. The differences between the measured beach profiles and the lidar were greatest in both the swash and the surf zone region (approximately 10% of the collected data) (Figure 6) where the reflectance at the water surface due to breaking waves and foam was greatest. Therefore, only the region of the histogram between -1 m and +1 m was considered when fitting the t-distribution. The mean difference between the measured profile data and the lidar data is taken as the mean of the t-distribution, μ (Table 2). The final offset between the 2006 lidar and the 2010 lidar was calculated as

$$\text{2010 lidar} + \mu_{2010} - \text{2006 lidar} - \mu_{2006} = \Delta\text{lidar} + \text{offset}$$

where:

$$\text{offset} = \mu_{2010} - \mu_{2006}.$$

Values are tabulated in Table 2.

Table 1. Data sets used for analysis.

SMS Project	Lidar Data	Beach Profile Data
Pinellas	2006 28 May – 20 June JALBTCX	Pinellas Profile Data USF 2006 June 8
	2010 20 June – 22 July JALBTCX	Pinellas Profile Data USF 2010 July 6
Manatee \ Sarasota	2006 28 May – 20 June JALBTCX	Longboat Key Profiles CP&E 2006 July 28
	2010 20 June – 22 July JALBTCX	Lido Key Profile CP&E 2010 June 2
Sarasota South	2006 28 May – 20 June JALBTCX	Lido Key Profiles CP&E 2006 May 9
	2010 20 June – 22 July JALBTCX	Siesta Key Profiles CP&E 2010 August 10

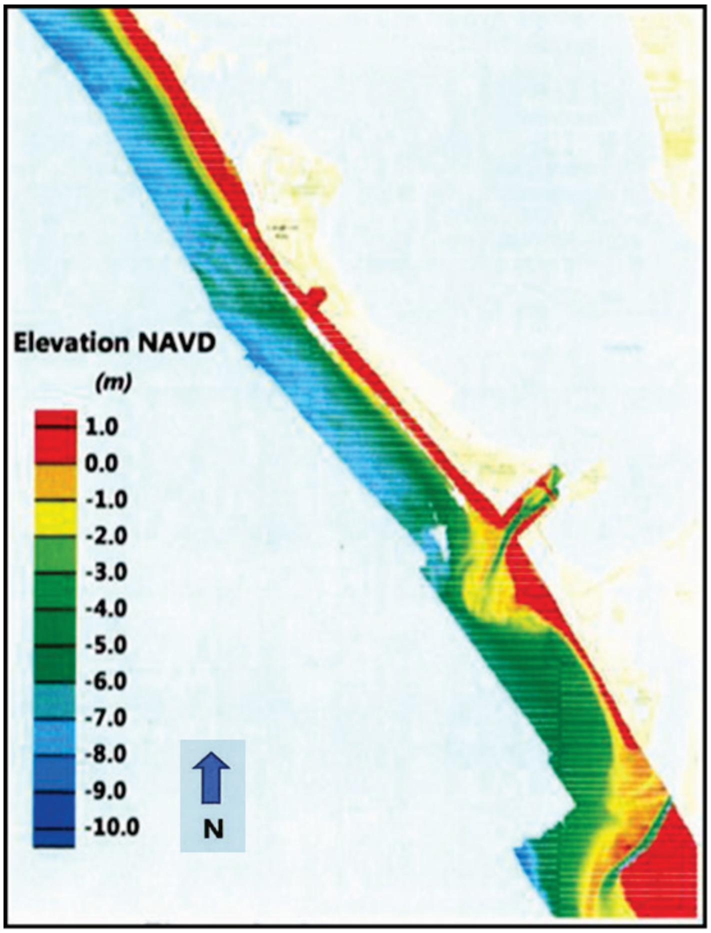


Figure 3. 2006 lidar data for Pinellas, Manatee/Sarasota, and south Sarasota Counties, FL.

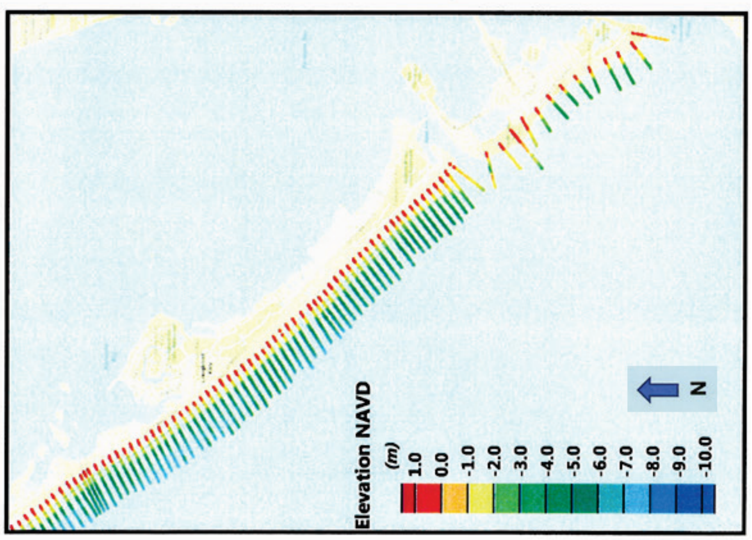


Figure 4. 2006 Survey beach profile data.

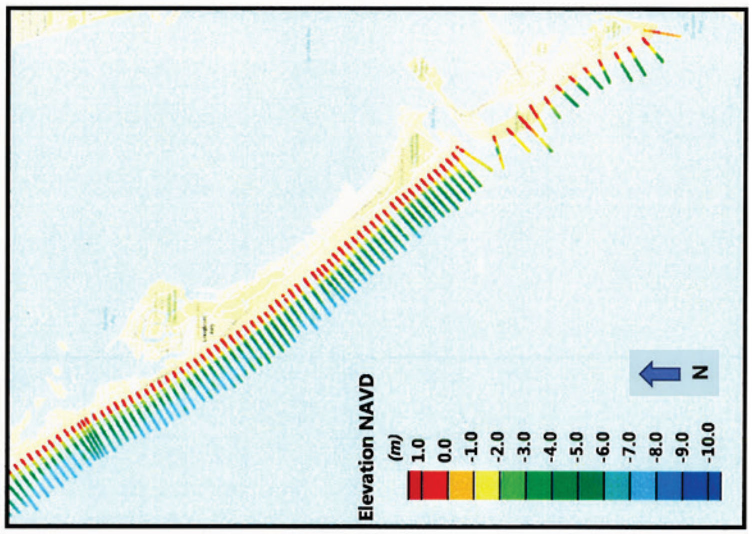


Figure 5. 2006 lidar data interpolated to profile data.

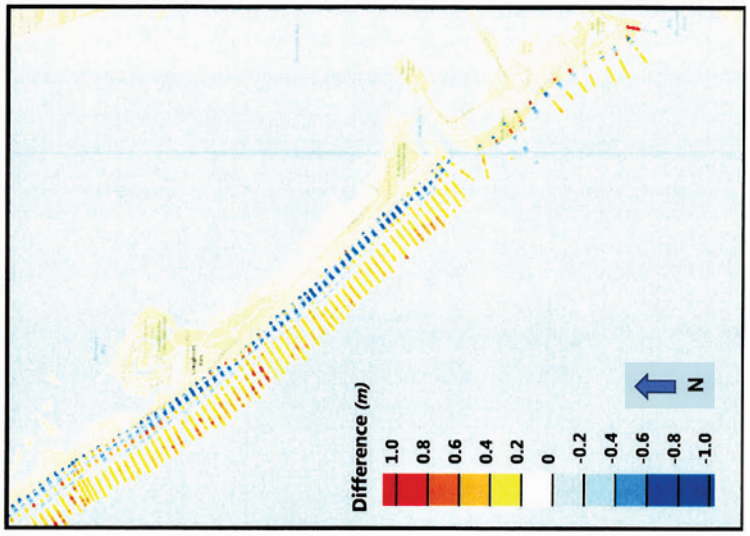


Figure 6. Differenced data: 2006 beach data minus 2006 lidar data.

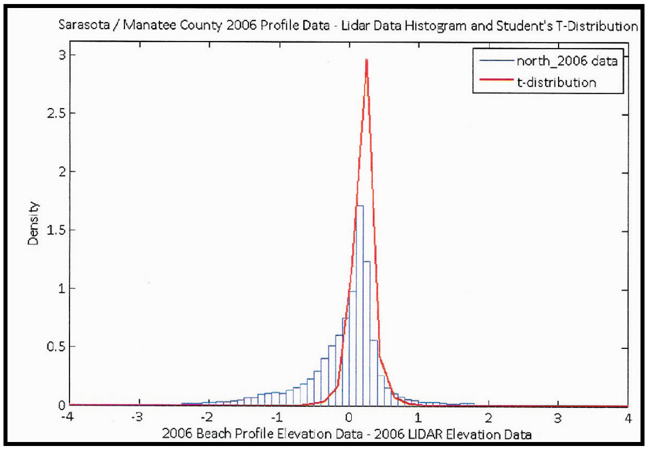


Figure 7. Student's t-distribution for Sarasota/ Manatee County 2006. μ = 0.194, σ^2 = 0.052.

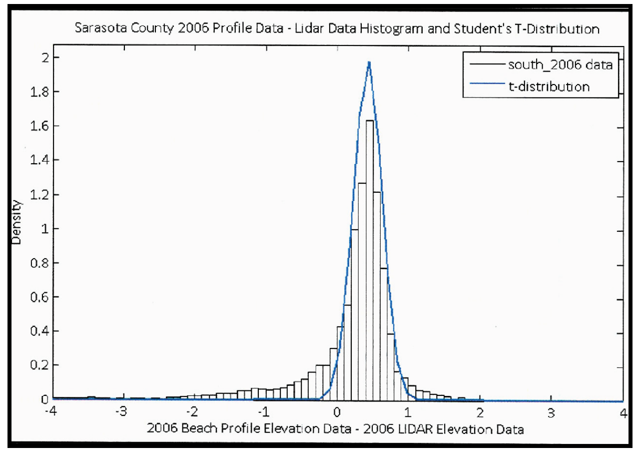


Figure 8. Student's t-distribution for Sarasota County South 2006. μ =0.432, σ^2 = 0.040.

Table 2. Results from Student's t-distribution and calculated offset.

SMS Project	μ	σ^2	offset
Pinellas 2006	0.24	0.015	+0.28 m
Pinellas 2010	0.52	0.030	
Manatee \ Sarasota 2006	0.194	0.052	-0.097 m
Manatee \ Sarasota 2010	0.097	0.063	
Sarasota South 2006	0.432	0.040	-0.286 m
Sarasota South 2010	0.146	0.029	

A map of the entire region was created in SMS (Figure 9). The map was delineated by profile lines and/or reaches in the alongshore and extended from the +1 m NAVD upland contour to the offshore extent of the lidar data (approximately 5 m to 7 m water depth). A Cartesian grid was created from the map using 10 m × 10 m grid cells. A final scatter set was created by differencing the 2006 lidar data from the 2010 lidar data and adding the appropriate offset based upon locale (Pinellas, Manatee\Sarasota, and Sarasota south). The scatter set was interpolated to the Cartesian grid. Volumes were calculated within SMS using a combination of the Map Module and the Cartesian grid (Figures 9 and 10) using the method described in Rosati et al. (2010).

RESULTS: The results of the calculations are shown in Table 3 and in Figures 11a,b,c. Beach volume density changes along the beach are presented in cubic yards per year per foot (cy/yr/ft) of beach.

Figure 9. Southwest Florida Gulf Coast SMS map module.

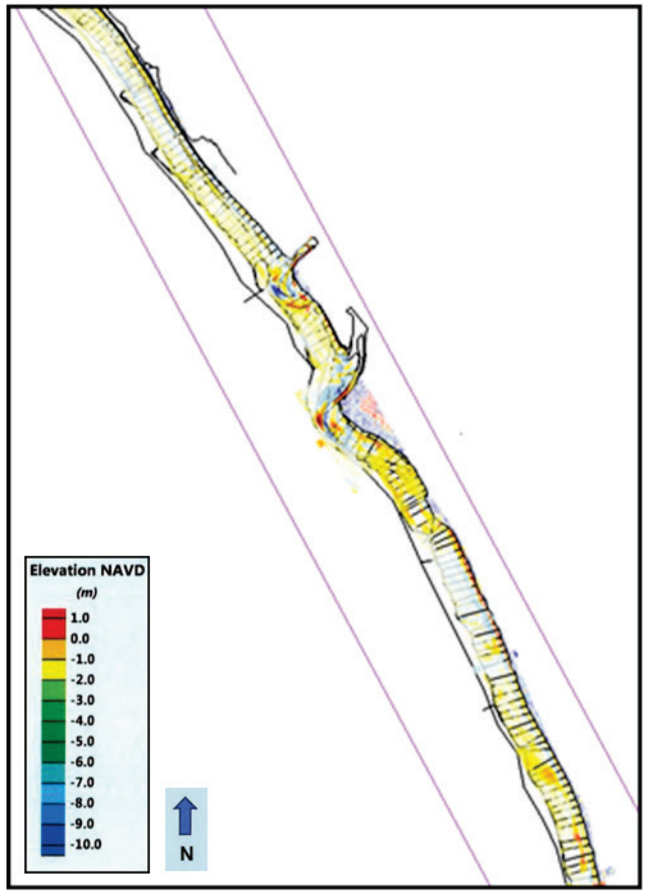
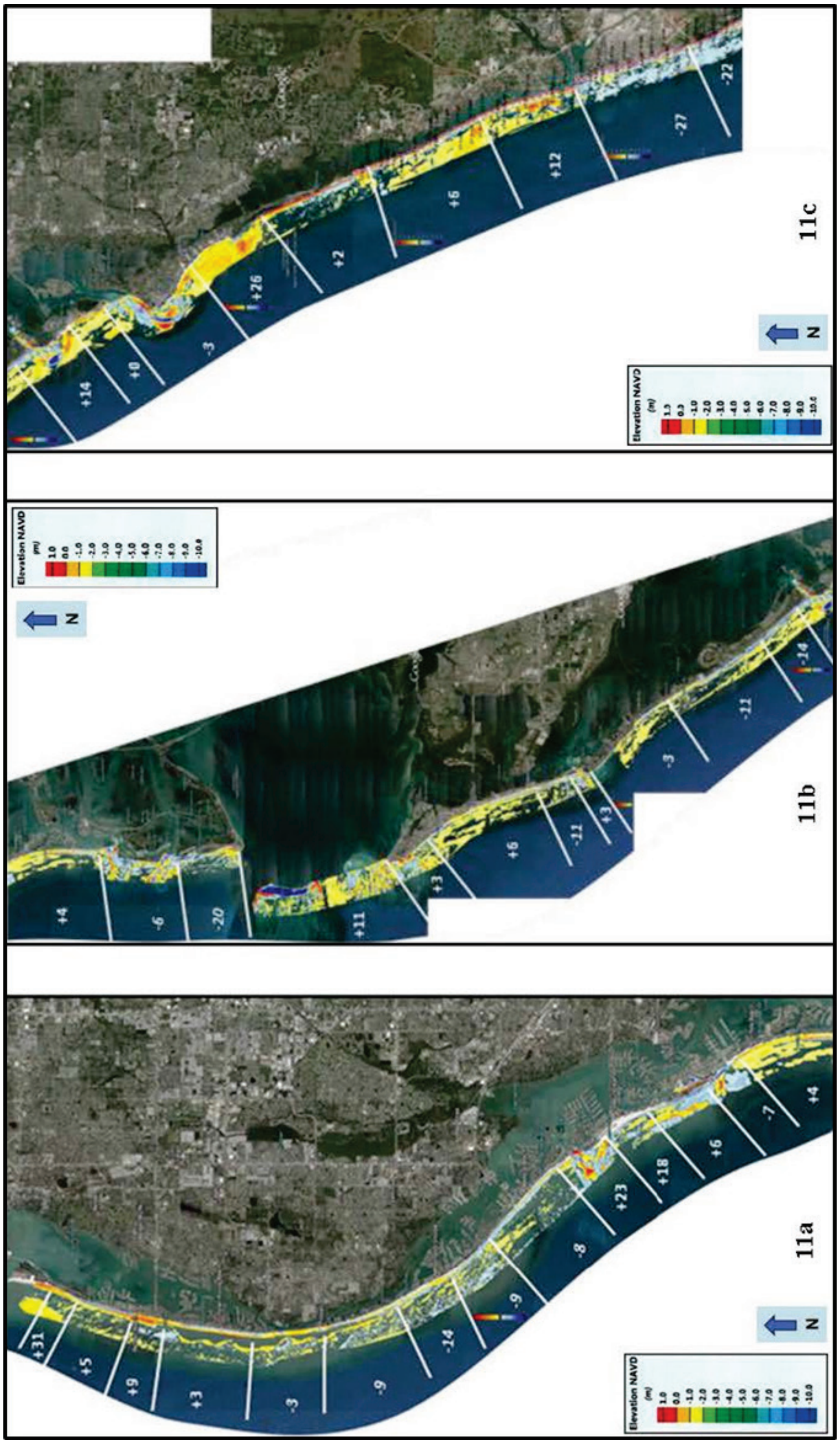


Figure 10. Southwest Florida Gulf Coast. Volume change grid. June 2006–July 2010.

Table 3. Volume and volume density changes.

Miles	FDEP R-Monument North	FDEP R-Monument South	Volume Change** 1000's cy	Beach Volume Density Change cy/yr/ft
0.4	R55	R57	67	**31**
1.9	R57	R65	37	**5**
2.6	R65	R69	34	**9**
4.9	R69	R81	35	**3**
6.4	R81	R89	-22	**-3**
8.5	R89	R100	-99	**-9**
9.7	R100	R107	-88	**-14**
10.9	R107	R113	-55	**-9**
13.1	R113	R124	-96	**-8**
14.4	R124	R131	158	**23**
15.4	R131	R136	102	**18**
16.8	R136	R143	40	**6**
17.6	R143	R148	-32	**-7**
21.0	R148	R166	72	**4**
23.8	INLET	INLET	-94	**-6**
26.3	R168	R181	-269	**-20**
31.2	R004	R001	285	**11**
32.8	R001	R11	28	**3**
37.3	R011	R034	135	**6**
38.6	R034	R041	-76	**-11**
40.1	R043	R050	103*	***15****
42.9	R050	R065	-41	**-3**
46.9	R065	R019	-227	**-11**
48.3	R019	R027	-104	**-14**
50.0	R027	R037	123	**14**
51.2	R037	R043	1	**0**
54.2	R043	R053	-44	**-3**
56.8	R053	R067	361	**26**
59.9	R067	R084	34	**2**
63.2	R084	R101	100	**6**
65.8	R101	R115	165	**12**
69.2	R115	R133	-469	**-27**
73.3	R133	R153	-478	**-22**

*Estimated (gap in 2006 lidar data).
**Adjusted for nourishment.



Figures 11a, 11b, and 11c. Southwest Florida Gulf Coast regional sediment budget volume density changes, adjusted for nourishment +/- cy/yr/ft. Contour colors denote volume changes (cool colors = erosion; warm colors = accretion). Developed using lidar. June 2006–July 2010.

DISCUSSION: Beach volume density changes using this method were compared with published studies that used beach profile surveys to calculate volume changes throughout the region. For Pinellas County, volume density changes were in the range of values calculated using beach profile data by Roberts (2012) and through the USACE SAJ (2010) third-year monitoring report. Calculated beach volume density changes in Manatee County using lidar data were different from those values reported in Coastal Planning & Engineering (2011). There was no effective way to make a comparison between the two studies. The offshore extent of the surveyed data was approximately 1,000 ft offshore, and the offshore extent of the lidar data was approximately 4,000 ft offshore. In both cases, for beach profile measurements as well as for the lidar data, it is clear that there are large volumes of sediment moving across the offshore boundary. This can become problematic for volume computations because the assumption is that there will be no sediment moving across the depth of closure. However, the general trends in Manatee County toward erosion and accretion were comparable. For Sarasota County, the beach volume density changes calculated from lidar data compared well with the historic volumetric analysis published in the Sarasota County Comprehensive Inlet Management Program (Coastal Technology Corporation et al. 2010).

Lessons learned from this work are that it is important and advantageous to use beach profile data to ground-truth lidar data, and beach profile data can be used to check volume computations when using lidar. However, and more importantly, through the use of lidar data, transport patterns and volume changes on a regional scale are readily visualized. Dominating processes and/or repeating patterns become comprehensible. For southwest Florida, it becomes very clear that the sediment transport processes, and the sediment sources and sinks, are dominated by inlets and their ebb shoals, which interrupt the relatively uniform shoreline. The understanding of attachment points for the ebb shoals, and the efficiency with which sediment is transported to down-drift beaches, will become important in the context of any engineering projects that exist along this particular stretch of shoreline. Additionally, it is clear from the lidar data that there are large volumes of sediment that can move across the offshore extent of the seafloor that has been mapped. Similar results were found offshore of Fire Island (Schwab et al. 2013). There, analysis of high-resolution seafloor mapping data suggests that onshore transport from the inner continental shelf is the source of sediment and thus resolves budget discrepancies in that region.

CONCLUSIONS: This CHETN documents the development of a method to ground-truth lidar data using measured beach profiles and demonstrates the use of SMS to calculate beach volume density changes over regional scales. The use of lidar data is advantageous over beach profile surveys because fine-scale features are resolved in the alongshore direction. The morphology and transport patterns are thus readily visualized. Additionally, lidar data are obtained synoptically over hundreds of miles, and their use eliminates errors in volume that can arise when using data sets that are taken from different time periods. On a regional scale, the dominant transport mechanisms and features become comprehensible. Using beach profile data to ground-truth lidar data can be a reliable method for regional sediment volume calculations.

ADDITIONAL INFORMATION: This Coastal and Hydraulics Engineering Technical Note (CHETN) was prepared by Kelly R. Legault, USACE Jacksonville District (SAJ). Funding for this study was provided by the USACE Regional Sediment Management (RSM) Program, a Navigation Research, Development, and Technology Portfolio program administered by

Headquarters, USACE. Additional information pertaining to the RSM Program can be found at the RSM website *http://rsm.usace.army.mil*.

Questions regarding this CHETN may be addressed to Kelly R. Legault (*Kelly.R.Legault@usace.army.mil*), SAJ Senior Coastal Engineer, Engineering Division. Additional information pertaining to the RSM program can be obtained from the USACE RSM Program Manager, Linda S. Lillycrop (*Linda.S.Lillycrop@usace.army.mil*).

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